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Research Paper
INT-365

August 1986

Predicting Site Index and Height for Selected Tree Species of Northern Idaho

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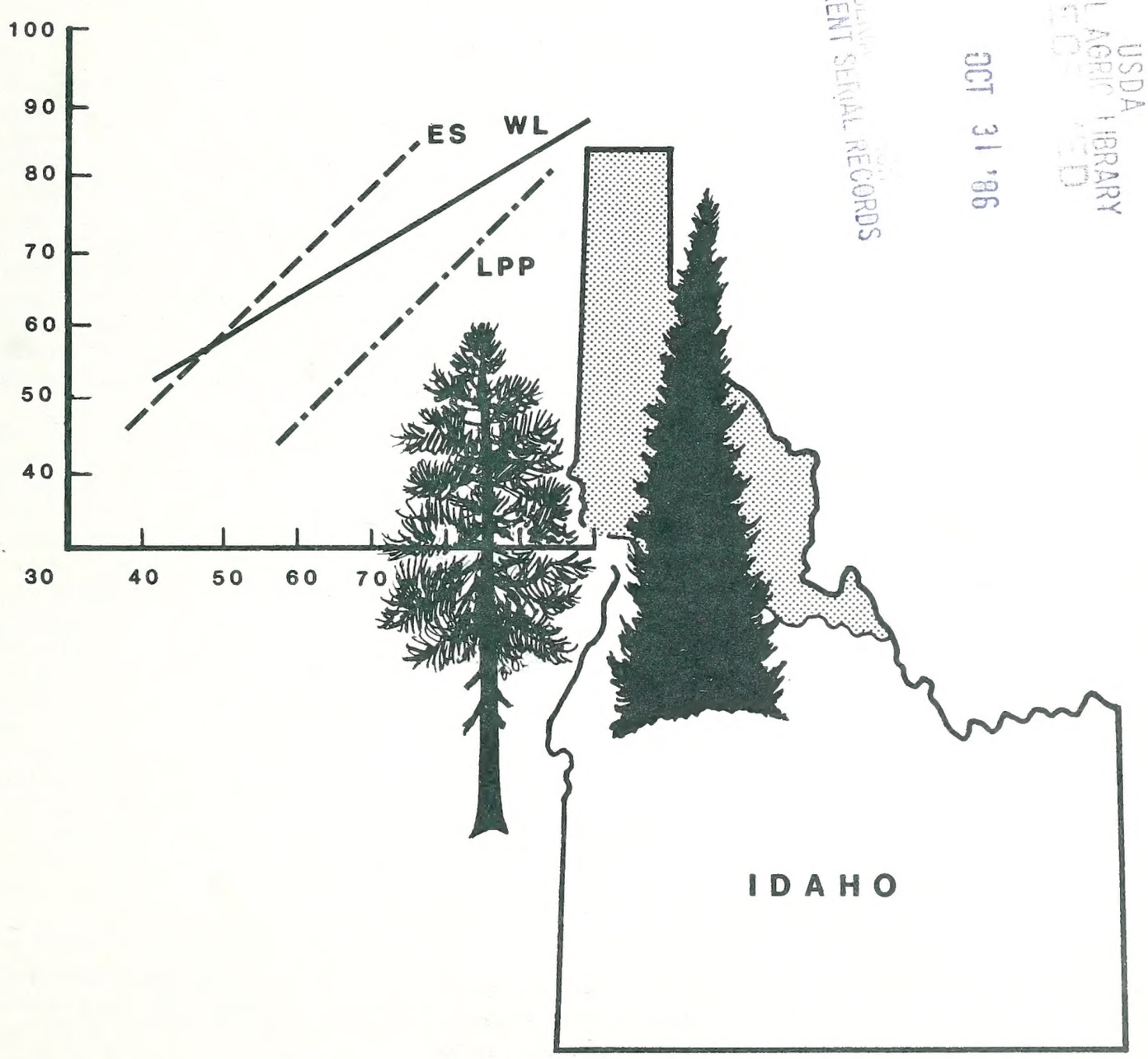

THE AUTHORS

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STEPHEN V. COOPER, research forester with the University of Montana during the study, is currently a volunteer with the Forest Service. He was a principal author of "Forest Habitat Types of Northern Idaho," from which the present study is derived. He shared responsibility for field sampling and analysis. He received B.S. (Union College, Schenectady, NY) and M.S. (State University of New York, Albany) degrees in biology, and a Ph.D. in botany (Washington State University).

ACKNOWLEDGMENTS

Major support for this study was provided by the Ecology Program of the Northern Region of the Forest Service, U.S. Department of Agriculture, through a cooperative agreement with the Intermountain Research Station.

We thank Mike Sweet (University of Montana), and Ken Neiman and Patricia Patterson (Clearwater National Forest) for providing supplementary data and field assistance.

August 1986
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INTRODUCTION

Given the manifold combinations of species, sites, and soils occurring in northern Idaho, and that growth rate, quantity, quality, and value of wood produced varies by species, foresters face complex decisions regarding species to favor on a given site. One important consideration is the relative productivity of each species. One useful estimate of productivity is site index: the height of dominant and codominant trees in a stand at an arbitrary (index) age, usually 50 years in the Western United States. Site index can be used to estimate volume growth through yield tables or as a variable in growth simulation models. Though its appropriateness has been questioned (Curtis and others 1974), the site index equation is often solved for height, which is then used as an estimate of stand height at ages other than the index age.

One method of estimating the site index of species absent from a site is the use of species on species regression equations or species comparison graphs. A number of such studies have been done in the East and Midwest (Foster 1959; Curtis and Post 1962; Carmean and Vasilevsky 1971; Carmean 1979; Carmean and Hahn 1983).

Copeland (1956) first demonstrated the utility of site index comparisons for the western white pine (*Pinus monticola*) type of northern Idaho. Deitschman and Green's (1965) study, also conducted in northern Idaho, stands as the most comprehensive of its type for the Northern Rockies. Except for western white pine, this study was done before site curves were available for most tree species in the interior West. Consequently, western white pine's site index was predicted as a function of height and age of other tree species, and environmental variables; conversely, height of the other species was predicted as a function of white pine site index, age, and environmental variables.

Our report presents equations for predicting the site index of one species from the measured site index of an associated species and equations for predicting the height of one species from its age and the measured site index of an associated species.

STUDY AREA

This study is based on data collected in the course of refining the northern Idaho habitat type classification (Cooper and others 1983). The study area extends from the Salmon River to the Canadian border, encompassing the Nezperce, Clearwater, and Idaho Panhandle National Forests, where the sampling effort was focused. The great diversity of forest environments found in this region has been described and classified by Daubenmire and Daubenmire (1968) and Cooper and others (1983).

FIELD PROCEDURES

Our methods generally followed those advocated by Pfister and Arno (1980) with respect to stand selection, sampling, and data analysis, with three important exceptions. First, stands that were not well stocked or approximately even-aged were deleted from site index analysis. Second, in order to more accurately estimate habitat type productivity (reflected by site index), our goal was to obtain height and age (at breast height, 4.5 feet) for five unsuppressed, undamaged dominant or codominant trees of each species in each stand. Third, soils were described according to Soil Survey Manual prescriptions (Soil Survey Staff 1975). We defined a stand to be a group of trees of similar age, structure, and species composition (canopy and undergrowth), occurring on an area of uniform topography, and centered on a circular 5,350-ft^2 sampling plot.

Site index values were estimated using equations or site index curves when equations were unavailable (table 1). We employed Clendenen's (1977) computer algorithm of Alexander's (1967) Engelmann spruce (*Picea engelmannii*) curves to estimate mountain hemlock (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa*) site indexes because site curves specific to species and region have not been developed for these two taxa. Engelmann spruce curves were chosen for extrapolation to the other two taxa because of their similarity in successional roles, undergrowth tolerance, and ecological amplitude.

In selecting site trees, no spacing or crown class limitations were imposed except that all site trees be dominant or codominant. This procedure departs from sampling procedures accompanying published site curves only in the case of western white pine. Haig's (1932) site index for white pine involved complex precriptions and the sampling of some trees that would not be considered site trees by our standards because of their inferior canopy position or low crown ratios. According to Monserud (1984a), who compared site index derived from three to four dominants to that obtained by Haig's specifications (13 to 20 trees), our western white pine site index values could be positively biased 20 percent or more.

Table 1.—Sources of curves used for computing site index[1]

Species	Estimated years to obtain breast height	Source of curve
Subalpine fir (*Abies lasiocarpa*)	([2])	Alexander (1967)
Grand fir (*Abies grandis*)	12	Stage (1959)
Western larch (*Larix occidentalis*)	5	Schmidt and others (1976)
Engelmann spruce (*Picea engelmannii*)	([2])	Alexander (1967)
Lodgepole pine (*Pinus contorta*)	7	Brickell (1970)
Western white pine (*Pinus monticola*)	5	Haig (1932)
Ponderosa pine (*Pinus ponderosa*)	5	Lynch (1958)
Douglas-fir (*Pseudotsuga menziesii*)	([2])	Monserud (1984b)
Mountain hemlock (*Tsuga mertensiana*)	([2])	Alexander (1967)

[1]All site curves based on a 50-year index age.
[2]Curves based on age at breast height were used.

Daubenmire (1961) and Lynch (1958) have warned against adding a constant number of years to breast height age to obtain total age for use with site curves requiring total age. They also indicated that the better the site, the fewer the years required to reach breast height. But, we lacked concrete data to indicate what variable number of years would be appropriate and therefore adopted the values specified by Pfister and others (1977) for western white pine, Stage (1959) for grand fir (*Abies grandis*), Schmidt and others (1976) for western larch (*Larix occidentalis*), Fiedler (1982) for lodgepole pine (*Pinus contorta*), and Daubenmire (1961) for ponderosa pine (*Pinus ponderosa*).

ANALYSIS

The data set was cleaned by discarding trees that were considerably shorter or older than the rest of the site trees in a stand. In a few cases, entire stands were rejected because of extreme variation in height or age of the site trees. First, we correlated site index between species. Scatter diagrams and least squares regressions were examined for all species combinations for which concomitant observations on six or more stands were available. A paired sample was composed of the mean site index of one species and the mean site index of an associated species. Examination of residuals indicated all associations were linear and more than 90 percent were statistically significant (95 percent confidence level).

We then grouped our data according to the number of site trees sampled in a stand. A minimum of two trees of each species per stand was generally necessary to provide sufficiently precise estimates of mean stand site indexes; a minimum of three site trees of each species further improved the regressions. Clearly, a larger number of site trees improves the reliability of the estimate of a stand's mean site index and consequently improves the predictability of the regression equations. For species combinations where enough pairs existed, regressions were restricted to stands with at least three site trees of each species per stand. The regression equations for the remaining species combinations were derived from stands with at least two site trees of each species per stand.

Second, height projection equations were computed by first considering the site index of species A and age of species B as observed values to predict the height of species B. It was assumed that the site index curves used to compute the site index of the observed species (species A) estimate site quality with negligible error. Without the assumption of measuring the age and site index with no error, the regression produces biased results.

The majority of the data was obtained from stands 45 to 120 years in age. The primary emphasis was to develop simple, flexible, empirical models for this age range, rather than biologically realistic models spanning the life span of a species. Thus, logarithmic, exponential, and second-order polynomial functions of age and site index were regressed on height. The general model form was chosen to be height predicted as a function of site index, age, and logarithmic function of age. Conformity to model assumptions was checked by examining plots of residuals versus predicted values. Coefficients of determination (R^2) and standard deviation about regression were calculated as measures of reliability; curves of estimated values generated by the regression equations were plotted over the site index curves of the dependent species to observe model behavior.

RESULTS AND DISCUSSION

Table 2 presents the site index regression equations intended for general use. Two equations are given for each species combination because the mathematics of least squares regression is such that the regression of A on B is the same as the regression of B on A only in producing equivalent coefficients of determination; the error term and the regression coefficients are almost invariably different.

Table 2.—Equations (and associated statistics) for predicting site index of a given species from the site index of associated species

List of observed species (X)	List of species (Y) whose site index is predicted	Number[1] of paired observations	Equations	Standard deviation about regression	Coefficient of determination	Site index range of observed species
				Feet	R^2	*Feet*
Douglas-fir	Engelmann spruce	22(3)	$Y = 9.56 + 0.98X$	6.62	0.67	39-76
	Grand fir	35(2)	$Y = -14.53 + 1.01X$	10.29	.56	58-94
	Lodgepole pine	41(3)	$Y = 25.00 + 0.56X$	4.15	.65	39-86
	Ponderosa pine	36(2)	$Y = 32.66 + 0.59X$	7.60	.33	50-89
	Subalpine fir	14(2)	$Y = 7.78 + 0.96X$	5.09	.84	39-78
	Western larch	50(3)	$Y = 26.06 + 0.62X$	3.49	.81	41-97
	Western white pine	24(2)	$Y = 5.01 + 0.88X$	7.46	.76	38-97
Engelmann spruce	Douglas-fir	22(3)	$Y = 14.05 + 0.69X$	5.54	.67	41-89
	Grand fir	11(2)	$Y = 0.23 + 0.70X$	9.28	.34	62-85
	Lodgepole pine	39(2)	$Y = 17.63 + 0.61X$	4.86	.76	37-89
	Mountain hemlock	16(2)	$Y = 6.32 + 0.72X$	7.93	.53	39-81
	Subalpine fir	36(2)	$Y = 2.51 + 0.93X$	6.44	.78	38-84
	Western larch	25(3)	$Y = 32.70 + 0.44X$	5.21	.46	48-84
	Western white pine	10(2)	$Y = 22.07 + 0.54X$	7.70	.56	41-90
Grand fir	Douglas-fir	35(2)	$Y = 40.73 + 0.56X$	7.66	.56	41-87
	Engelmann spruce	11(2)	$Y = 46.73 + 0.48X$	7.67	.34	33-70
	Lodgepole pine	14(2)	$Y = 43.69 + 0.38X$	7.97	.33	41-84
	Western larch	21(2)	$Y = 45.77 + 0.42X$	5.66	.51	39-84
	Western white pine	7(2)	$Y = 10.39 + 0.99X$	8.90	.34	55-71
Lodgepole pine	Douglas-fir	41(3)	$Y = -7.24 + 1.16X$	5.99	.65	44-77
	Engelmann spruce	39(2)	$Y = -6.09 + 1.24X$	6.91	.76	37-76
	Grand fir	14(2)	$Y = 1.29 + 0.88X$	12.14	.33	56-86
	Mountain hemlock	15(2)	$Y = -6.10 + 0.98X$	4.31	.77	37-59
	Ponderosa pine	9(3)	$Y = 17.45 + 0.81X$	4.23	.34	53-67
	Subalpine fir	26(2)	$Y = -18.72 + 1.42X$	7.56	.78	37-77
	Western larch	34(3)	$Y = -12.13 + 1.28X$	4.76	.74	48-76
	Western white pine	16(2)	$Y = -42.43 + 1.81X$	8.46	.69	44-68
Mountain hemlock	Engelmann spruce	16(2)	$Y = 21.06 + 0.75X$	8.11	.53	25-66
	Lodgepole pine	15(2)	$Y = 15.92 + 0.78X$	3.85	.77	26-54
	Subalpine fir	24(2)	$Y = 8.88 + 0.93X$	5.66	.73	26-66
	Western larch	8(2)	$Y = 15.20 + 0.89X$	7.74	.42	36-56
Ponderosa pine	Douglas-fir	36(2)	$Y = 27.62 + 0.56X$	7.45	.33	53-91
	Lodgepole pine	9(3)	$Y = 31.77 + 0.42X$	3.06	.34	58-72
Subalpine fir	Douglas-fir	14(2)	$Y = 2.92 + 0.88X$	4.89	.84	49-88
	Engelmann spruce	36(2)	$Y = 11.54 + 0.84X$	6.13	.78	36-87
	Lodgepole pine	26(2)	$Y = 21.84 + 0.55X$	4.72	.78	34-88
	Mountain hemlock	24(2)	$Y = 4.53 + 0.78X$	5.20	.73	28-75
	Western larch	14(2)	$Y = 22.88 + 0.63X$	6.27	.64	45-88
	Western white pine	7(2)	$Y = 11.51 + 0.78X$	9.20	.59	49-82
Western larch	Douglas-fir	50(3)	$Y = -21.07 + 1.31X$	5.09	.81	47-87
	Engelmann spruce	25(3)	$Y = 3.73 + 1.05X$	8.04	.46	42-75
	Grand fir	21(2)	$Y = -27.20 + 1.21X$	9.58	.51	58-89
	Lodgepole pine	34(3)	$Y = 22.64 + 0.58X$	3.18	.74	42-82
	Mountain hemlock	8(2)	$Y = 20.47 + 0.47X$	5.64	.42	42-69
	Subalpine fir	14(2)	$Y = 1.55 + 1.01X$	7.92	.64	42-85
	Western white pine	27(2)	$Y = -15.09 + 1.19X$	7.12	.74	47-86
Western white pine	Douglas-fir	24(2)	$Y = 12.12 + 0.86X$	7.38	.76	38-95
	Engelmann spruce	10(2)	$Y = 8.85 + 1.03X$	10.62	.56	41-77
	Grand fir	7(2)	$Y = 40.34 + 0.34X$	5.24	.34	56-84
	Lodgepole pine	16(2)	$Y = 34.26 + 0.38X$	3.87	.69	40-91
	Subalpine fir	7(2)	$Y = 18.72 + 0.76X$	9.02	.59	41-81
	Western larch	27(2)	$Y = 27.28 + 0.62X$	5.16	.74	38-97

[1]Minimum number of trees of both species per stand in parentheses.

Table 3 presents height projection equations for general use. The natural logarithm transformation of age was found to be the nonlinear transformation most consistently producing low standard errors from the regression equation and large explained variances. In addition, when residuals were examined, no curvilinear trends were detected, and the error components appeared to have equal variances over the range of the data. The behavior of equations with natural logarithm terms displayed a gradual decrease in height growth over time, whereas other transformations were occasionally erratic.

Some species comparisons that produced site index regression equations were not used in height projection regressions because sample size was inadequate or the range in ages was limited. These equations have been omitted.

Comparative Study Results

Despite this study's attempt to encompass a broader range of environments and a more extensive geographical area than have previous studies of this nature, our results (tables 2 and 3) are nonetheless comparable to those of the preceding studies. Deitschman and Green's (1965) regression equations predicting western white pine site index from environmental variables, heights, and ages of associated species explained 37 to 50 percent of the variation in site index, with standard deviation about regression ranging from 9.7 to 12.0 feet. For western white pine, our results (table 2) for these statistical measures were, respectively, 34 to 76 percent and 7.1 to 9.2 feet. Their regression equations predicting tree heights for other species from western white pine site

Table 3.—Projecting age-specific height for a given species from the site index of associated species

List of observed species (X)	List of species (Y) whose height is predicted	Number of paired observations	Equations[1]	Standard deviation about regression	Coefficient of determination	Age range of predicted species	Site index range of observed species
				Feet	R^2	*Years*	*Feet*
Douglas-fir	Engelmann spruce	22	$Y = -295.68 + 1.43X - 0.12A + 70.54Ln(A)$	7.49	0.89	50-156	39-76
	Grand fir	35	$Y = -114.41 + 1.10X + 0.61A + 22.31Ln(A)$	12.71	.71	40-127	59-100
	Lodgepole pine	41	$Y = -287.69 + 1.02X - 0.32A + 77.13Ln(A)$	5.65	.82	47-143	39-86
	Ponderosa pine	36	$Y = -252.34 + 0.81X - 0.37A + 74.44Ln(A)$	8.66	.69	42-200	51-90
	Western larch	50	$Y = -268.95 + 0.91X - 0.25A + 74.75Ln(A)$	5.72	.89	40-155	41-100
	Western white pine	24	$Y = -447.29 + 1.18X - 0.84A + 124.29Ln(A)$	8.34	88	44-110	39-98
	Subalpine fir	14	$Y = -178.87 + 1.25X + 0.14A + 40.47Ln(A)$	6.33	.89	39-145	39-78
Engelmann spruce	Douglas-fir	22	$Y = -173.81 + 0.94X + 0.03A + 44.50Ln(A)$	5.92	.93	45-162	41-90
	Grand fir	11	$Y = -58.32 + 1.08X + 0.56A + 7.76Ln(A)$	7.00	.93	44-127	50-85
	Lodgepole pine	39	$Y = -153.92 + 0.99X - 0.02A + 39.83Ln(A)$	7.12	.82	52-144	38-90
	Mountain hemlock	16	$Y = -164.30 + 0.92X + 0.01A + 40.47Ln(A)$	11.24	.82	41-163	39-81
	Subalpine fir	36	$Y = -229.69 + 1.02X - 0.30A + 62.18Ln(A)$	7.23	.85	40-145	39-85
	Western larch	25	$Y = -136.81 + 0.77X + 0.01A + 40.04Ln(A)$	6.80	.91	40-163	48-90
Grand fir	Douglas-fir	35	$Y = -298.76 + 0.63X - 0.37A + 90.08Ln(A)$	9.29	.77	44-159	41-107
	Engelmann spruce	11	$Y = -180.93 + 0.72X + 0.02A + 53.88Ln(A)$	11.13	.79	47-145	33-70
	Western larch	21	$Y = -116.80 + 0.49X + 0.01A + 43.15Ln(A)$	8.06	.74	50-167	39-84
Lodgepole pine	Douglas-fir	41	$Y = -232.14 + 1.30X - 0.17A + 58.50Ln(A)$	6.63	.84	44-144	45-78
	Engelmann spruce	39	$Y = -294.86 + 1.33X - 0.43A + 77.86Ln(A)$	8.14	.86	44-200	38-78
	Mountain hemlock	15	$Y = -147.85 + 1.02X - 0.02A + 35.91Ln(A)$	5.20	.85	41-130	38-61
	Subalpine fir	26	$Y = -106.02 + 1.30X + 0.14A + 22.24Ln(A)$	7.99	.74	39-145	38-78
	Western larch	34	$Y = -296.44 + 1.64X - 0.36A + 73.48Ln(A)$	7.09	.81	53-147	49-78
	Western white pine	16	$Y = -149.83 + 1.82X + 0.14A + 28.51Ln(A)$	6.16	.82	44-135	45-69
Mountain hemlock	Engelmann spruce	16	$Y = -238.78 + 1.03X - 0.34A + 67.93Ln(A)$	11.44	.83	44-146	26-67
	Lodgepole pine	15	$Y = -192.92 + 1.12X - 0.29A + 54.90Ln(A)$	6.16	.75	51-144	38-61
	Subalpine fir	24	$Y = -207.57 + 1.14X - 0.26A + 56.77Ln(A)$	7.15	.85	43-155	26-67
Ponderosa pine	Douglas-fir	36	$Y = -122.57 + 0.81X + 0.05A + 35.18Ln(A)$	8.27	.70	48-178	38-92
Subalpine fir	Engelmann spruce	36	$Y = -209.79 + 1.03X - 0.08A + 54.31Ln(A)$	8.03	.88	44-152	28-87
	Lodgepole pine	26	$Y = -233.38 + 0.82X - 0.34A + 66.77Ln(A)$	7.22	.75	51-147	28-87
	Mountain hemlock	24	$Y = -148.02 + 1.01X + 0.12A - 33.76Ln(A)$	6.99	.87	41-147	28-74
Western larch	Douglas-fir	50	$Y = -331.12 + 1.47X - 0.32A + 80.77Ln(A)$	6.09	.89	44-162	47-90
	Engelmann spruce	25	$Y = -460.10 + 1.05X - 0.82A + 127.25Ln(A)$	8.69	.90	44-162	43-75
	Grand fir	21	$Y = -413.43 + 1.12X - 0.81A + 116.53Ln(A)$	11.68	.65	40-107	58-90
	Lodgepole pine	34	$Y = -174.42 + 0.84X - 0.07A + 48.90Ln(A)$	4.84	.86	54-143	43-83
	Western white pine	27	$Y = -281.61 + 1.79X - 0.06A + 61.78Ln(A)$	7.55	.92	44-146	47-86
Western white pine	Douglas-fir	24	$Y = -495.87 + 1.18X - 0.84A + 133.79Ln(A)$	10.66	.77	45-145	39-97
	Western larch	27	$Y = -571.46 + 1.17X - 1.03A + 155.76Ln(A)$	6.41	.92	46-165	39-97

[1]X is the mean stand site index of the observed species; A is the age of the species whose height is being protected; Ln(A) is the natural logarithm of A.

index, age, transformations of age and site index, and environmental variables explained 87 to 99 percent of the variation in tree height, with standard deviation about regression ranging from 3.4 to 8.2 feet. We are able to explain 77 to 92 percent of the variance in height of other species (table 3) from white pine site index and the age of the predicted species without employing environmental variables as additional predictors; standard deviation about regression ranged from 6.4 to 10.7 feet.

Wiant and Porter (1966) used simple linear regression to predict site index of Douglas-fir (*Pseudotsuga menziesii*), redwood (*Sequoia sempervirens*), and associated hardwoods from site indexes of other tree species in northern California. They used eight to 33 plots per regression and obtained explained variances from 13 to 55 percent. Carmean (1979), Carmean and Hahn (1983), and Carmean and Vasilevsky (1971) compared site indexes in several areas of the Midwest and upper Midwest and found linear relations between each species pair. Seven to 278 plots were used for the comparisons (notably larger than our sample size range), with one to five trees of each species on a plot. Their equations explained 40 to 91 percent of the variation in site index; standard deviation from the regression line ranged from 2.5 to 11.3 feet. Our results (table 2) show explained variances ranging from a low of 33 percent (Douglas-fir/ponderosa pine comparison) to a high of 84 percent (Douglas-fir/subalpine fir comparison); deviations about regression ranged from 3.1 feet (predicted lodgepole pine site index from western larch) to 12.1 feet (predicted grand fir site index from lodgepole pine).

Using Regression Models

The site index regression models are displayed in figures 1 through 9. The independent variable (the site index of the species used to predict) is plotted on the X-axis versus the dependent variable (the predicted site index of the specific species) on the Y-axis. For instance, to use figure 1, obtain a mean site index for Douglas-fir, say 60. Locate this value on the X-axis and read up to the western larch line and then directly across to the Y-axis, the predicted western larch site index being 63. The user is warned not to extrapolate beyond the range of the independent variable (as denoted by the length of the line) because these are empirically derived equations. Extrapolation beyond the range of the data may lead to gross errors of over- or underestimation.

The direct comparison of site index of one species to that of another must consider their respective index ages, whether it is age at breast height, or total age. Curves based on breast height age, in essence, regard the site tree to be 0 years old at the time it reaches breast height, whereas curves based on total age assume the tree to be some fixed number of years old by the time it reaches breast height. Thus, the site index of two different species that are 50 years old at breast height and of equal height will not be equal if the number of years added to reach breast height is not equal. Table 1 shows the number of years added to breast height age to obtain total age for those curves requiring total age. A further consideration when comparing tree heights at ages other than the index age is the shape of the site index curves. None of the curves employed in this study are identical; these curves reflect species-specific growth patterns. Consequently, when comparing species at ages other than 50, different heights may be registered for trees that are of equal height at the index age. The magnitude of these differences may be appreciable at older ages.

Use of Site Index Graphs

Examination of site index comparison graphs (figs. 1 through 9) reveals that the relationship of one species site index to that of its associates may change differentially in response to site quality, even when a 1:1 correspondence is observed over part of the range of site index. For example, Douglas-fir responds strongly to differences in site quality; the increase in its height growth rate from poor to good sites is comparatively greater than that exhibited by some of its associates. This observation is reflected in the steeper slopes of the Douglas-fir regression lines (compare figs. 2, 3, 7, 8, and 9). Western white pine also demonstrates a similar sensitivity to site quality (figs. 1, 4, and 8). Engelmann

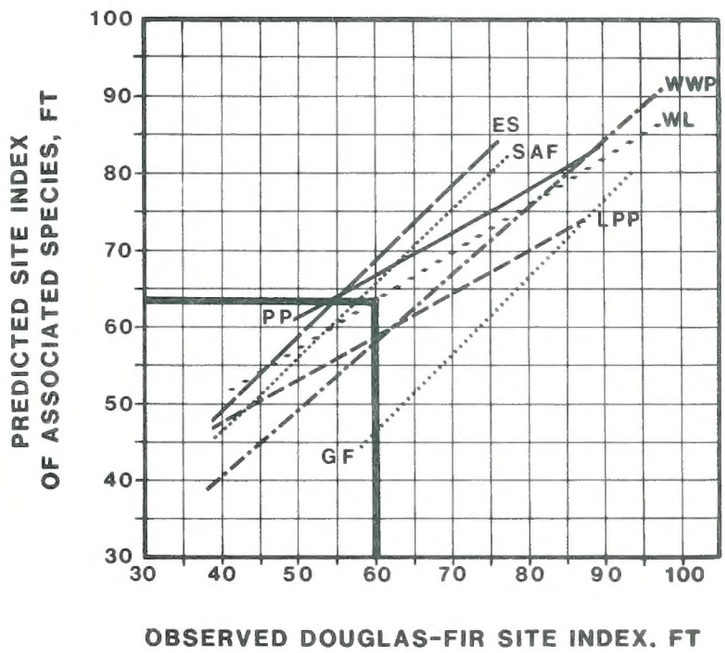


Figure 1.—Using Douglas-fir site index (x-axis) to predict that of associated species (y-axis). The diagrammed example case shows an observed Douglas-fir site index of 60 predicts a western larch site index of 63. In this and all following figures the species abbreviations are: ES, Engelmann spruce; GF, grand fir; DF, Douglas-fir; PP, ponderosa pine; WL, western larch; SAF, subalpine fir; LPP, lodgepole pine; WWP, western white pine; MH, mountain hemlock.

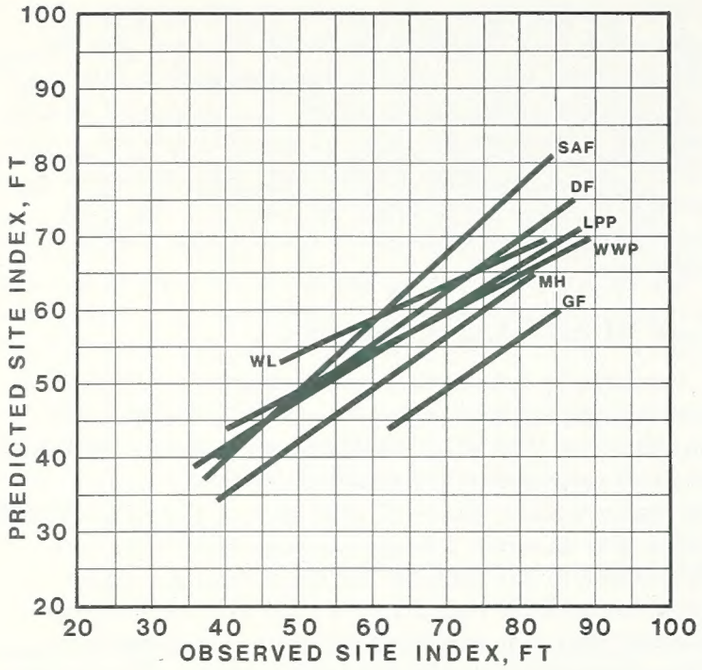


Figure 2.—Using Engelmann spruce site index (x-axis) to predict that of associated species (y-axis).

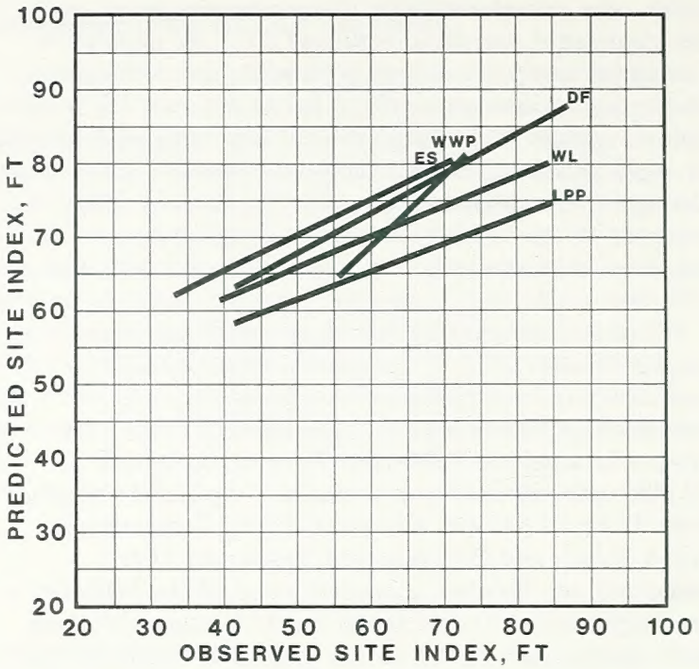


Figure 3.—Using grand fir site index (x-axis) to predict that of associated species (y-axis).

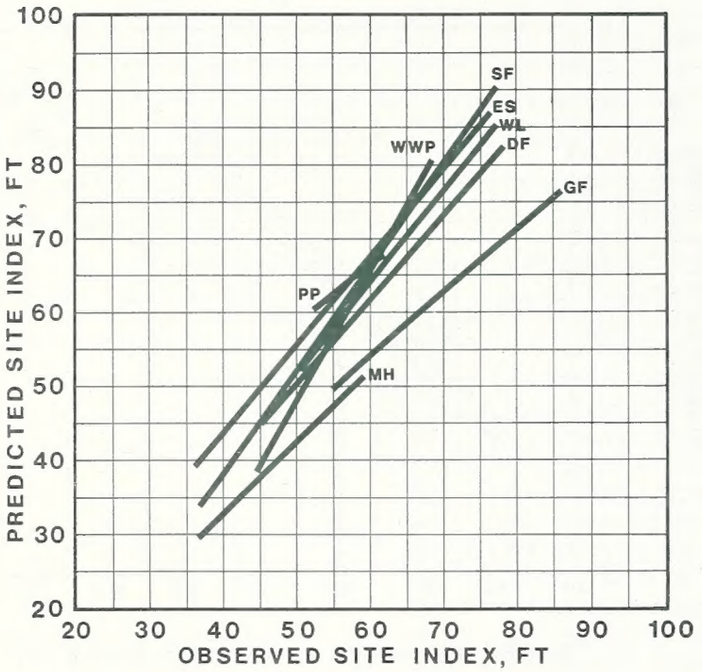


Figure 4.—Using lodgepole pine site index (x-axis) to predict that of associated species (y-axis).

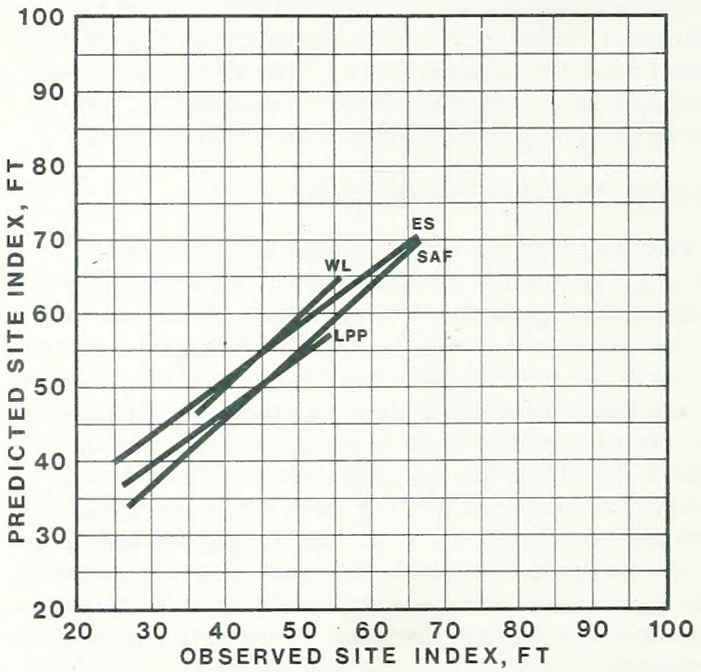


Figure 5.—Using mountain hemlock site index (x-axis) to predict that of subalpine fir (y-axis).

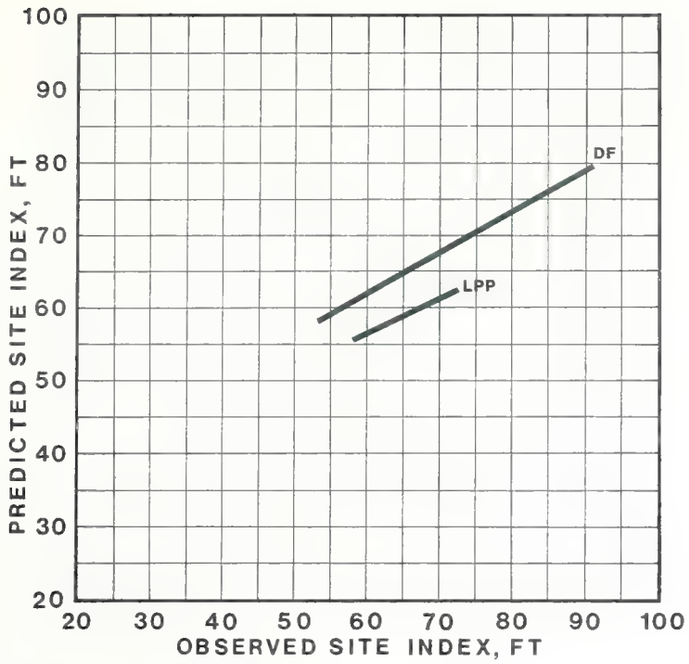


Figure 6.—Using ponderosa pine site index (x-axis) to predict that of associated species (y-axis).

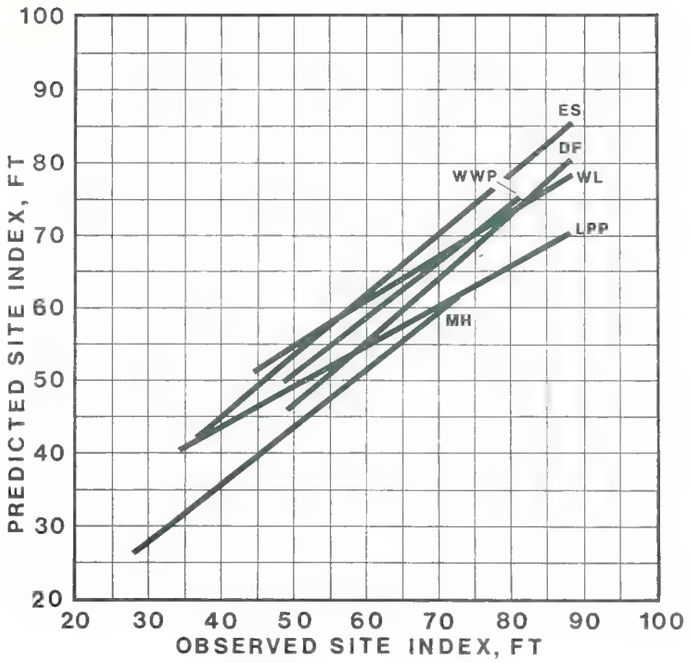


Figure 7.—Using subalpine fir site index (x-axis) to predict that of associated species (y-axis).

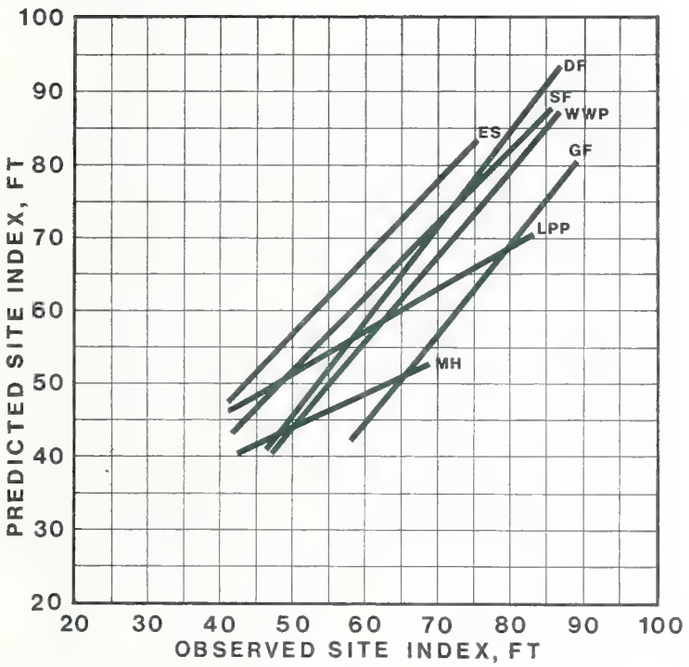


Figure 8.—Using western larch site index (x-axis) to predict that of associated species (y-axis).

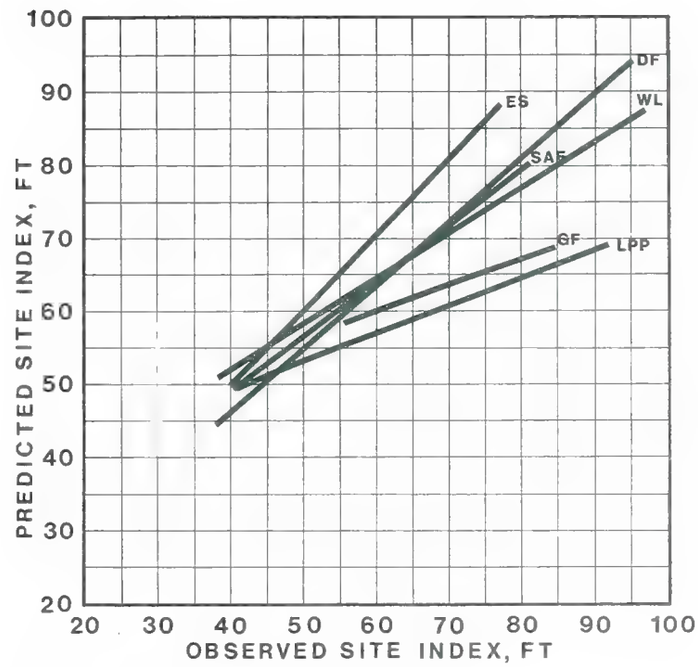


Figure 9.—Using western white pine site index (x-axis) to predict that of associated species (y-axis).

spruce and subalpine fir height growth responds strongly to site quality, although both species are capable of growing on poor-quality sites (cold, high-elevation sites) (figs. 1, 2, and 9). Western larch is somewhat less sensitive to site quality (figs. 1, 2, 7, and 9) and able to grow on all but the coldest subalpine sites, the dry portion of the Douglas-fir series, and the entire ponderosa pine series. Lodgepole pine is less sensitive yet (figs. 1, 3, 7, 8, and 9). The grand fir regression lines demonstrate unexplained erratic behavior. But figures 1 and 8 (Douglas-fir and western larch, for which large samples exist) show grand fir quite responsive to site quality. Overall, Engelmann spruce generally has the highest observed site index (figs. 1, 3, 4, 7, 8, and 9), a result attributed as much to its site index being computed on breast height age as to its superior height growth. With the exception of mountain hemlock, grand fir and lodgepole pine show the lowest observed site indexes (figs. 1, 7, 8, and 9). These observations do not reflect on height potential at any age other than index age; in fact, grand fir is often the tallest species on moderate sites.

Use of height projection equations (table 3) is limited to the recorded age range of the species to be predicted and the observed site index range of the predictor species. The equations are empirically derived from these specific ranges; do not extrapolate equations beyond the given ranges because their behavior may not correspond to expected height growth patterns.

Figures 10 through 18 portray height growth potentials of associated species, using table 3 equations to project height growth for each of the predicted species associated with a single observed species. For example, figure 12 corresponds to a stand in which the observed grand fir site index is 60; projected heights for Douglas-fir, Engelmann spruce, and western larch are graphed over only the observed age range of each species. The following site quality terms, which have been arbitrarily defined in respect to northern Idaho sites and applied to all species, are employed here only to facilitate the ensuing discussion: low, site indices <55; medium, site indices $\geqq 55$ but <70; high, site indices $\geqq 70$.

Figures 10 and 17 show that grand fir and western white pine have the greatest height growth potential on medium and better sites. Their heights are generally 5 to 10 feet taller than those of Douglas-fir, western larch, and Engelmann spruce over the age range 40 to 110 years. Douglas-fir, western larch, and Engelmann spruce are similar in height potential, with western larch somewhat taller at ages less than 70 years (figs. 11 and 12). Engelmann spruce is taller on high sites (fig. 10), whereas western larch is comparatively taller on medium sites (fig. 13). All three species demonstrate good height growth on medium to high sites.

Lodgepole pine is shown to be as tall as or taller than associated species at young ages on poor sites (figs. 15 and 16), but not nearly as tall on medium and better sites (figs. 11 and 17). Ponderosa pine also shows rapid early growth, followed by a more rapid deceleration of height growth than its associates (fig. 10). If height were the sole determinant of rotation age, then ponderosa pine apparently lends itself to short rotation management on warm, dry sites. Lodgepole pine may be similarly managed on cold and/or dry sites.

Subalpine fir has height growth comparable to associated species at younger ages, but its height is less after 70 years (figs. 11 and 12). Mountain hemlock height growth is consistently slower than all other species (figs. 11, 13, and 15).

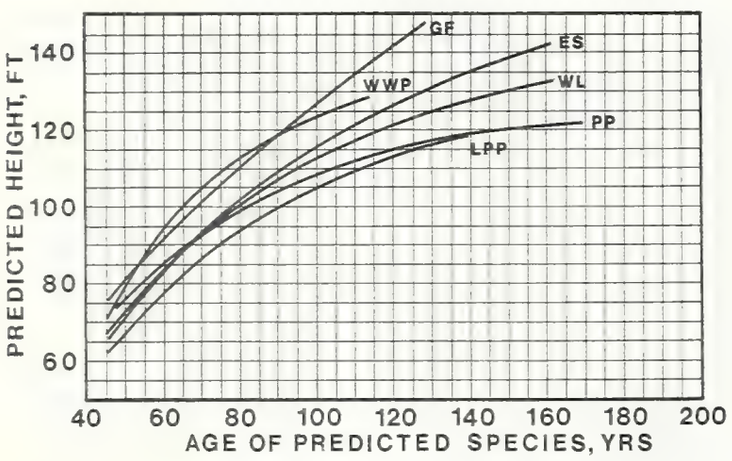


Figure 10.—Douglas-fir at site index 70 is used to project the heights of Engelmann spruce, grand fir, lodgepole pine, ponderosa pine, western larch, and western white pine; heights of the associated species (predicted variables) are projected over their sampled age ranges.

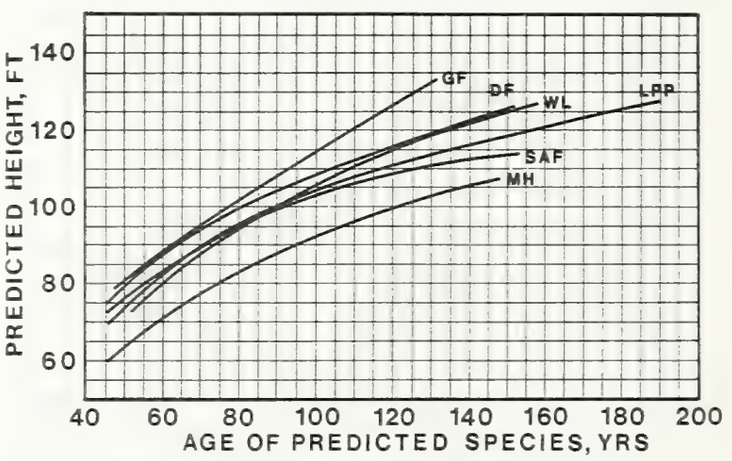


Figure 11.—Engelmann spruce at site index 70 is used to project the heights of Douglas-fir, grand fir, lodgepole pine, mountain hemlock, subalpine fir, and western larch; heights of the associated species are projected over their sampled age ranges.

Model Validation

The validity of our height growth models is most legitimately ascertained by comparing them to height growth models developed by stem analysis procedures. Monserud's (1984b) Douglas-fir height growth model developed for virtually the same geographic area as our study qualifies as the most appropriate one for comparison; we assume that Monserud's height growth curves represent the true Douglas-fir growth pattern against which our height projection curves will be compared. Figure 19a shows the height growth pattern predicted by Monserud's (1984b) equations for three site index values, 40, 60, 80 (poor, medium, and high quality sites); for these Douglas-fir site index values we have used corresponding western larch site index values (derived from table 2) and Douglas-fir age (table 3) to predict Douglas-fir height. From ages 50 to 160 years (the stipulated age range of equation applicability) the degree of correspondence between the curves appears high. Our equation overestimates Douglas-fir height by an average of 4.0 feet at site index 80 and underestimates by 1.5 feet at site index 60 and 2.4 feet at site index 40. As age increases beyond 150 years, our model produces underestimates of increasing magnitude for all site index values. Figure 19b compares Monserud's (1984b) curves

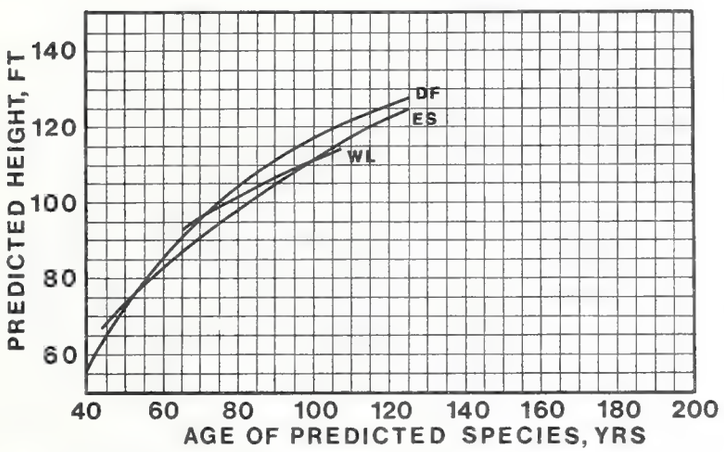


Figure 12.—Grand fir at site index 60 is used to project the heights of Douglas-fir, Engelmann spruce, and western larch; heights of the associated species are projected over their sampled age ranges.

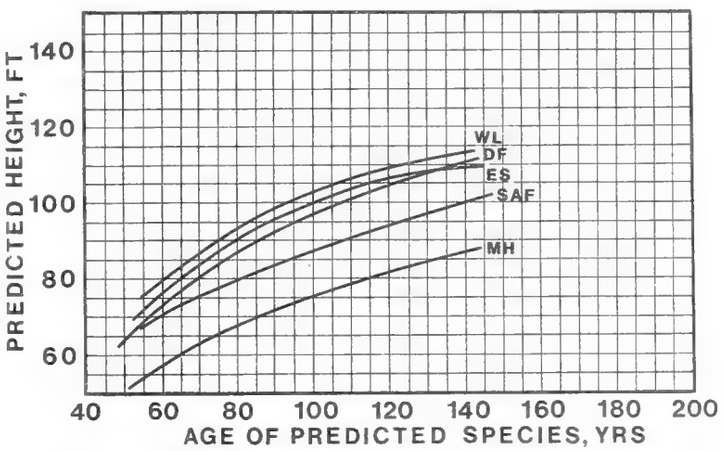


Figure 13.—Lodgepole pine at site index 60 is used to project the heights of Douglas-fir, Engelmann spruce, mountain hemlock, subalpine fir, and western larch; heights of the associated species are projected over their sampled age ranges.

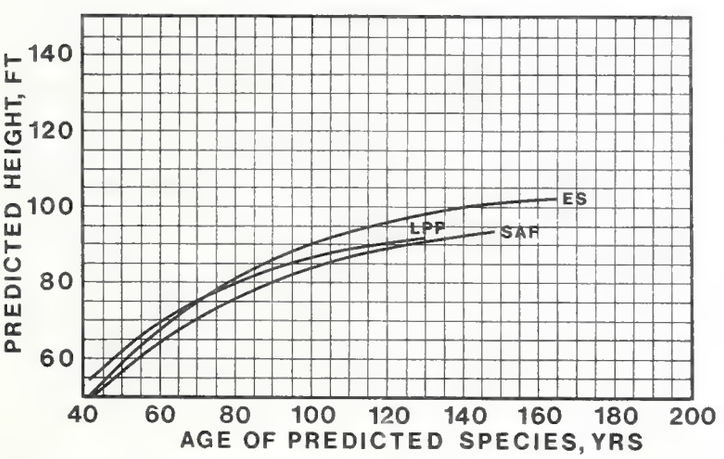


Figure 14.—Mountain hemlock at site index 50 is used to project the heights of Engelmann spruce, lodgepole pine, and subalpine fir; heights of the associated species are projected over their sampled age ranges.

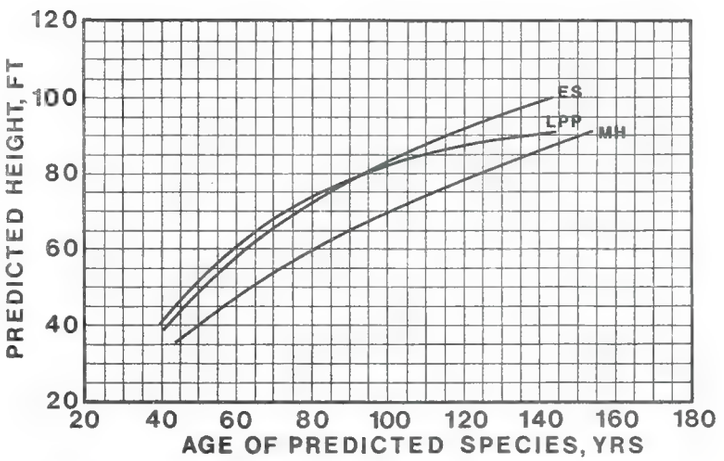


Figure 15.—Subalpine fir at site index 50 is used to project the heights of Engelmann spruce, lodgepole pine, and mountain hemlock; heights of the associated species are projected over their sampled age ranges.

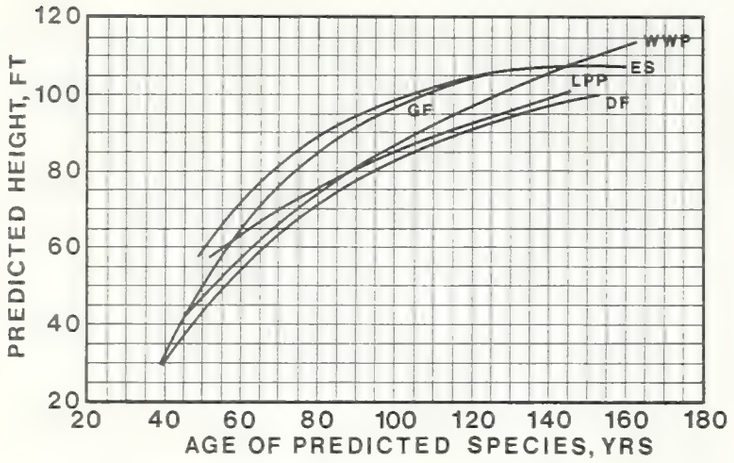


Figure 16.—Western larch at site index 50 is used to project the heights of Douglas-fir, Engelmann spruce, grand fir, lodgepole pine, and western white pine; heights of the associated species are projected over their sampled age ranges.

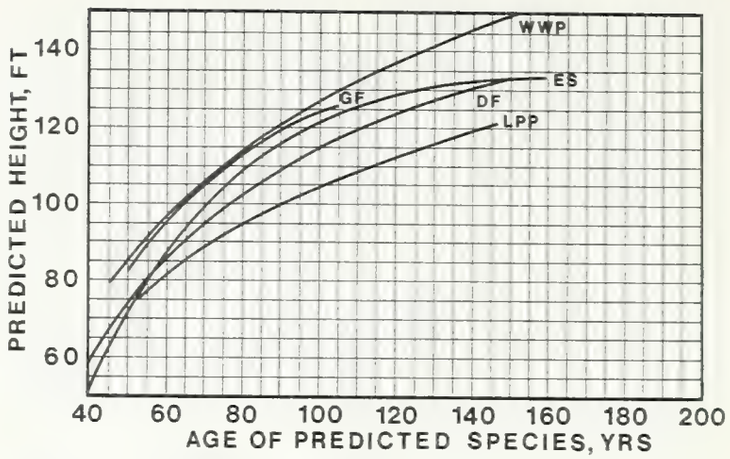


Figure 17.—Western larch at site index 70 is used to project the heights of Douglas-fir, Engelmann spruce, grand fir, lodgepole pine, and western white pine; heights of the associated species are projected over their sampled age ranges.

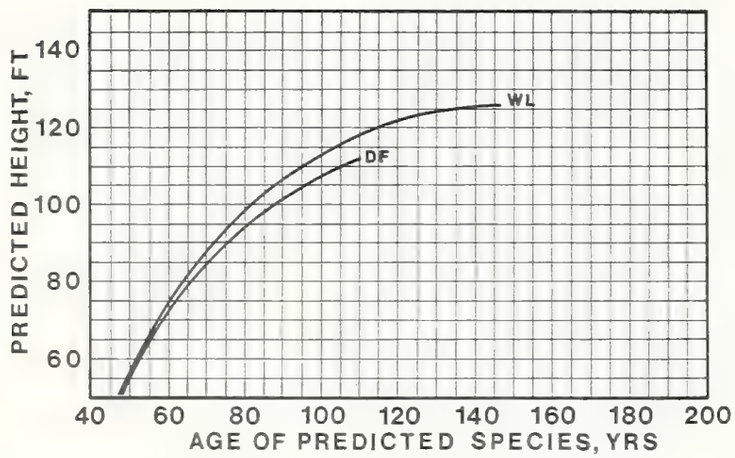


Figure 18.—Western white pine is used to project the heights of Douglas-fir and western larch; heights of the associated species are projected over their sampled age ranges.

with our projection of Douglas-fir height growth generated from observed Engelmann spruce site index. Despite the better statistics for Engelmann spruce than for western larch equations (table 3), comparison of figures 19a to 19b shows Engelmann spruce site index values to be poorer predictors of Douglas-fir height growth. There is a greater discrepancy between the predicted Douglas-fir height growth curve and the "actual" Douglas-fir height growth curve of Monserud when using Engelmann spruce as a predictor than when using western larch.

Site index and height projection comparisons are useful tools in choosing the best species for a site. Other factors such as stocking, timber value, optimum rotation age, susceptibilty to insect attack, and disease resistance must also be considered. For instance, although western white pine and grand fir are generally projected to be the fastest growing species on a given site, the land manager may favor the relatively slower growing Douglas-fir or western larch because of the susceptiblity of western white pine to blister rust and the lower timber value and higher disease risk of grand fir.

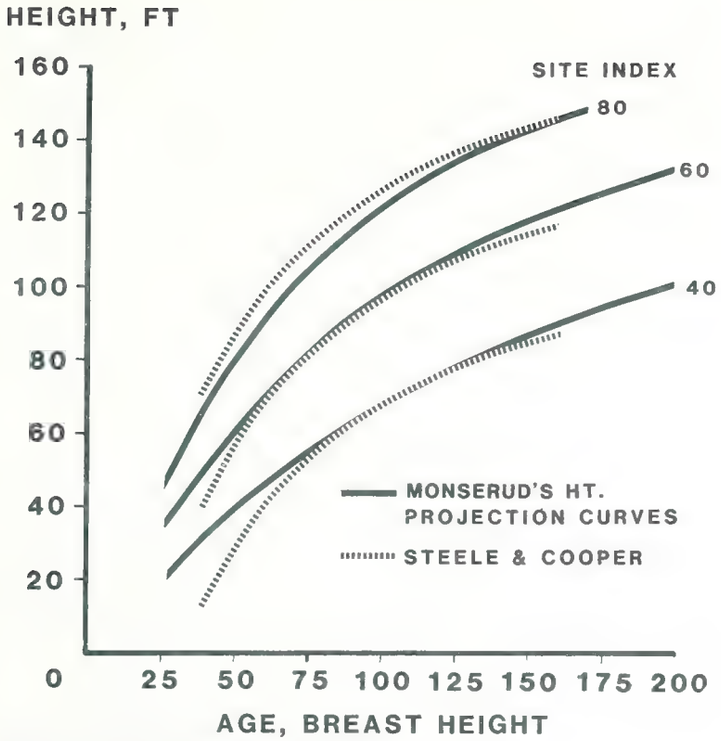


Figure 19a.—Comparison of Monserud's (1984) curves projecting Douglas-fir height growth to those generated from western larch site index and Douglas-fir age, employing authors' equations (table 3).

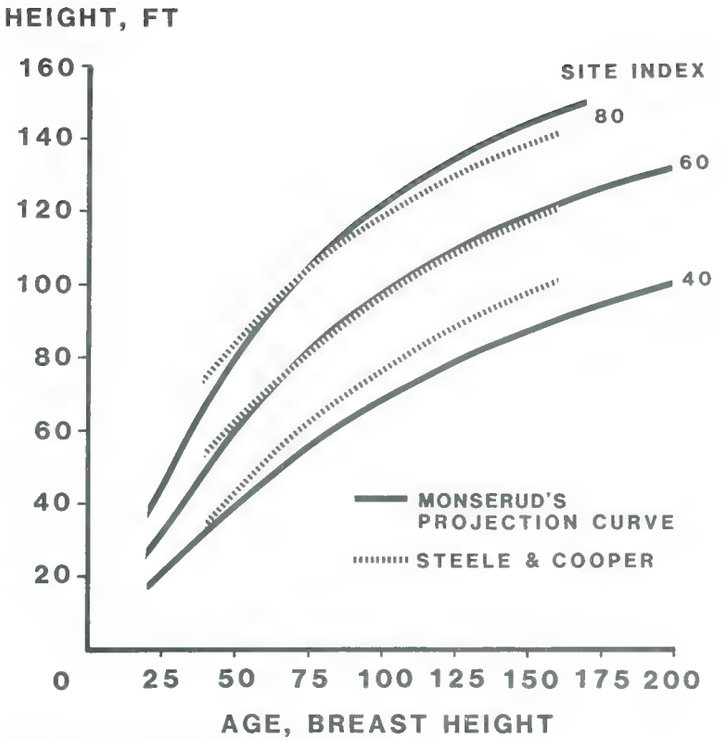


Figure 19b.—Comparison of Monserud's (1984) curves projecting Douglas-fir height growth to those generated from Engelmann spruce site index and Douglas-fir age, employing authors' equations (table 3).

SUMMARY OF METHOD TO PREDICT SITE INDEX AND HEIGHT

To predict the stand site index or height of a species from associated species, the following methodology should be followed. Select all sample trees from a stand uniform in overstory species composition, age structure, habitat type, and topography. Even-aged stands (no more than a 20-year range in the age of the dominant and codominant trees) (Alexander 1967) are preferred. Uneven-aged stands may be sampled, avoiding or rejecting trees that have suffered past suppression. Select two to five site trees of the predictor species (used to predict site index of the desired species). Site trees should be dominant or codominant, undamaged (no broken or forked tops, excessive sweep or crook, or disease), and unsuppressed (normal pattern of ring growth on the increment core) (Alexander 1967). Compute the site index of each site tree from the site curves presented in appendix A and average the values to arrive at a mean stand site index. Estimation of total age must be done with the values given in table 1.

Site index of an associated species can be computed from the equations in table 2 or read from the graph of the independent species (figs. 1 through 9) if the mean stand site index falls within the range of site index given for the independent variable in table 2. If more than one species is sampled and used to estimate the site index of the desired species, then a more reliable estimate can be made by averaging the site index estimates.

Height of an associated species can be predicted from the equations in table 3, provided: (1) the mean stand site index of the observed species is within the range of site index given for the predictor variable, and (2) the age at which the absent species height is to be predicted is also within the age range given for the predicted variable.

REFERENCES

Alexander, Robert R. Site indexes for lodgepole pine, with corrections for stand density. Research Paper RM-24. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 7 p.

Alexander, Robert R. Site indexes for Engelmann spruce in the Central Rocky Mountains. Research Paper RM-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 7 p.

Brickell, James E. Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. Research Paper INT-75. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 22 p.

Carmean, Willard H. Site index comparisons among northern hardwoods in northern Wisconsin and upper Michigan. Research Paper NC-169. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1979. 12 p.

Carmean, Willard H.; Hahn, Jerold T. Site comparisons for upland oaks and yellow-poplar in the Central States. Journal of Forestry. 81(11): 736-739; 1983.

Carmean, Willard H.; Vasilevsky, Alexander. Site-index comparisons for tree species in northern Minnesota. Research Paper NC-65. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1971. 8 p.

Clendenen, Gary W. Base-age conversion and site index equations for Engelmann spruce stands in the Central and Southern Rocky Mountains. Research Note INT-223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 6 p.

Cooper, Stephen; Neiman, Kenneth; Steele, Robert. Forest habitat types of northern Idaho, review draft, May 1983. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station and Northern Region; 1983. 210 p.

Copeland, Otis L., Jr. Preliminary soil-site studies in the western white pine type. Research Note No. 33. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1956. 4 p.

Curtis, R. O.; DeMars, D. J.; Herman, F. R. Which dependent variable in site index-height-age regressions? Forest Science. 20: 74-87; 1974.

Curtis, R. O.; Post, B. W. Comparative site indices for northern hardwoods in the Green Mountains of Vermont. Journal Series Paper No. 107. Burlington, VT: Vermont Agricultural Experiment Station; 1962. 6 p.

Daubenmire, R. Vegetative indicators of rate of height growth in ponderosa pine. Forest Science. 7: 24-34; 1961.

Daubenmire, R.; Daubenmire, J. B. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington Agricultural Experiment Station; 1968. 104 p.

Deitschman, Glenn H.; Green, Alan W. Relations between western white pine site index and tree height of several associated species. Research Paper INT-22. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1965. 27 p.

Fiedler, Carl E. Regeneration of clearcuts within four habitat types in western Montana. In: Baumgartner, D., ed. Site preparation and fuels management on steep terrain: Proceedings of the symposium; 1982; Spokane, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1982: 139-147.

Foster, Ralph W. Relation between site indexes of eastern white pine and red maple. Forest Science. 5: 279-291; 1959.

Haig, I. T. Second-growth yield, stand, and volume tables for the western white pine type. Technical Bulletin No. 323. Washington, DC: U.S. Department of Agriculture; 1932. 67 p.

Lynch, D. W. Effects of stocking on site measurement and yield of second-growth ponderosa pine in the Inland Empire. Research Paper INT-56. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1958. 36 p.

Monserud, R. A. Problems with site index: an opinionated review. In: Bockheim, J., ed. Forest land classification: experiences, problems, perspectives: Symposium proceedings. Madison, WI: University of Wisconsin, Cooperative Extension; [in press, paper presented 3/20/84].

Monserud, Robert A. Height growth and site index curves for inland Douglas-fir based on stem-analysis data and forest habitat type. Forest Science. 4(30): 943-965; 1984.

Pfister, R. D.; Arno, S. F. Classifying forest habitat types based on potential climax vegetation. Forest Science. 26: 52-70; 1980.

Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Schmidt, W. C.; Shearer, R. C.; Roe, A. L. Ecology and silviculture of western larch forests. Technical Bulletin 1520. Washington, DC: U.S. Department of Agriculture, Forest Service; 1976. 96 p.

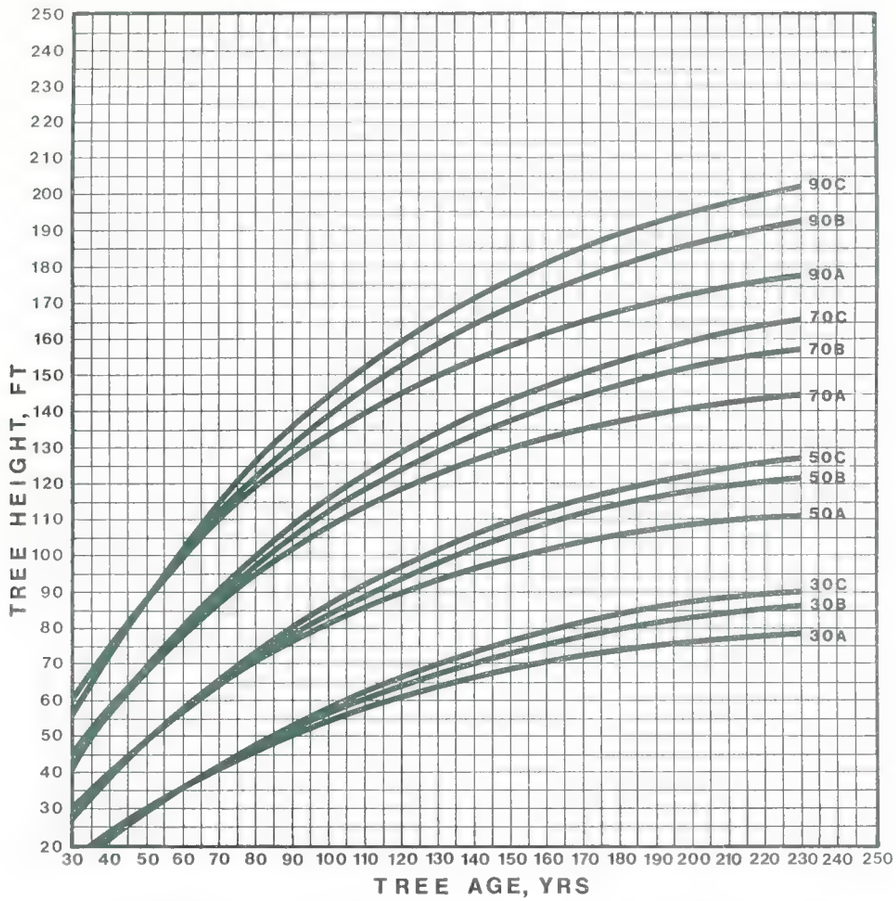
Soil Survey Staff. Soil taxonomy. Agriculture Handbook 436. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1975. 754 p.

Stage, A. R. Site curves for grand fir in the Inland Empire. Research Note No. 71. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1959. 4 p.

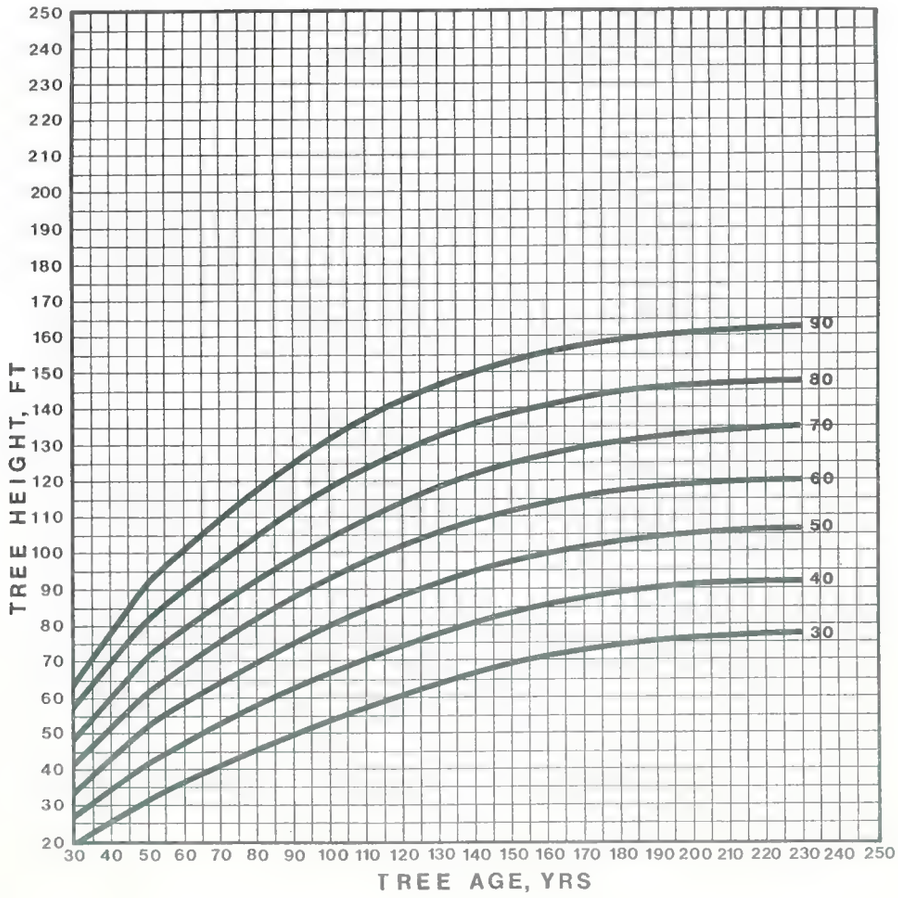
Wiant, Harry V., Jr.; Porter, Dennis R. Site index comparisons for redwood, Douglas-fir, and some associated hardwoods. Journal of Forestry. 64: 541-543; 1966.

APPENDIX A. SITE INDEX CURVES FOR COMMON NORTHERN IDAHO TREE SPECIES, ARRANGED ALPHABETICALLY BY COMMON NAME BEGINNING WITH DOUGLAS-FIR

Douglas-fir. Monserud's (1984) site curves; index age is 50 years at breast height. Three sets of site curves are presented: (A) curves for stands in the western hemlock or subalpine fir series; (B) curves for stands in the grand fir or western redcedar (*Thuja plicata*) series, or stands for which the series is not known; (C) curves for the Douglas-fir series.



Engelmann spruce. Alexander's (1967) site curves converted to index age 50 years at breast height by Clendenen (1977).



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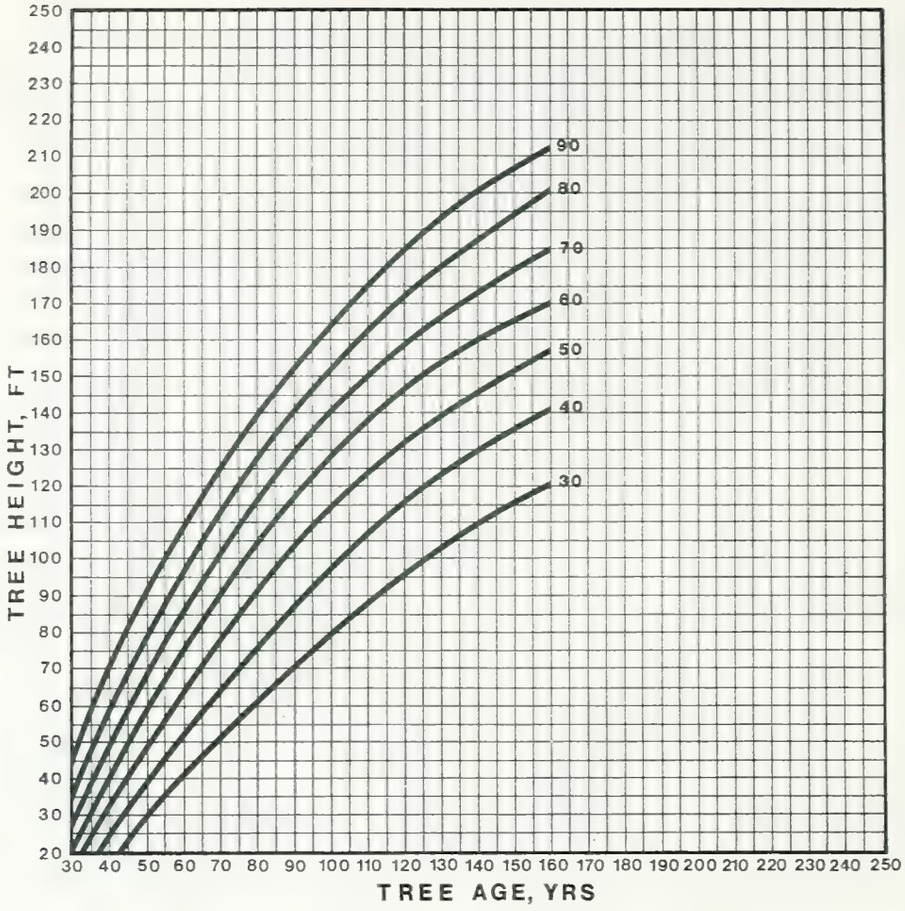
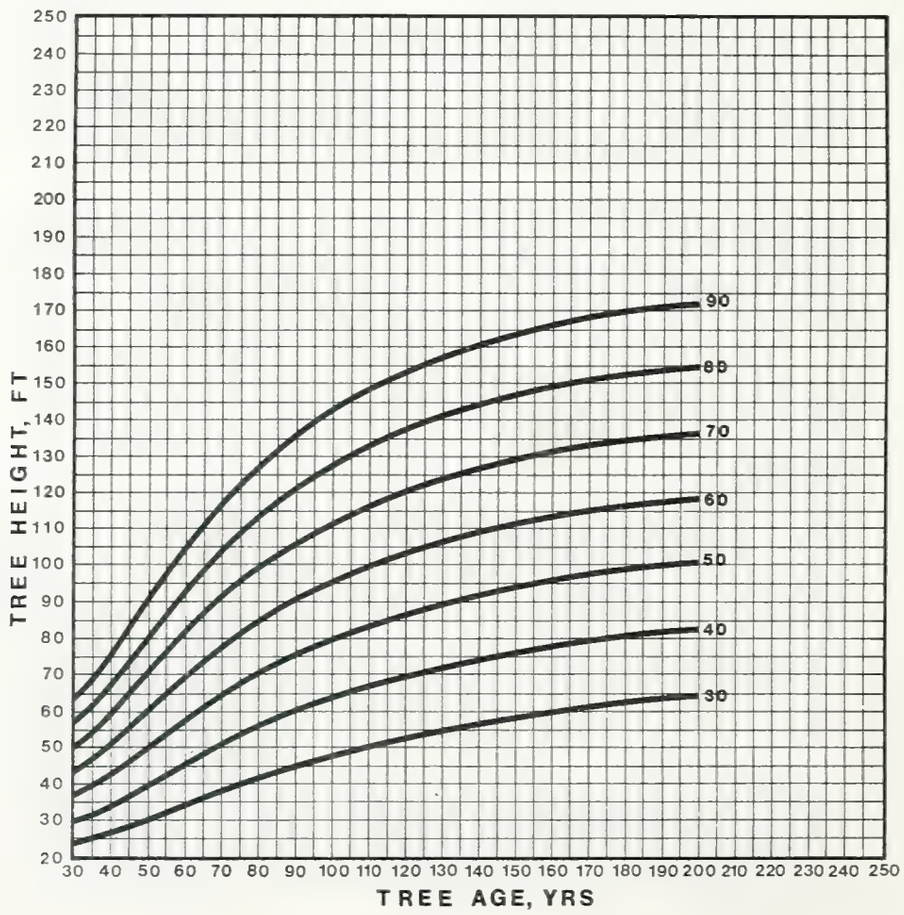


Grand fir. Stage's (1959) site curves; index age is 50 years total age (12 years added to breast height age).



Lodgepole pine. Alexander's (1966) site curves; index age is 50 years total age (5 years added to breast height age).

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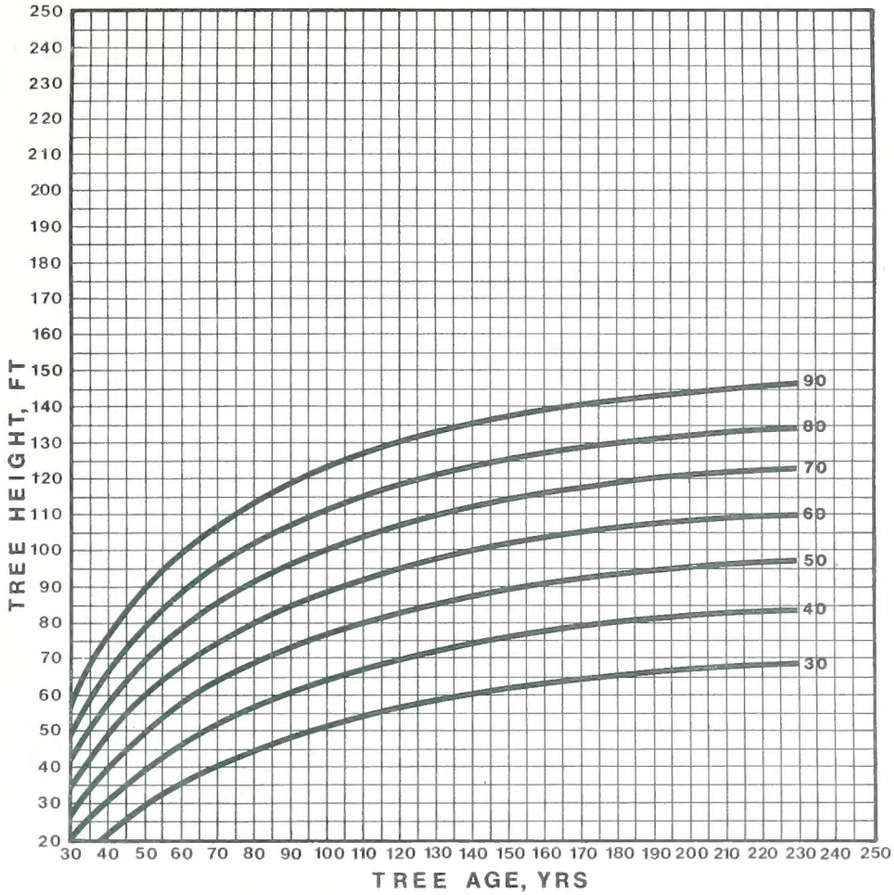
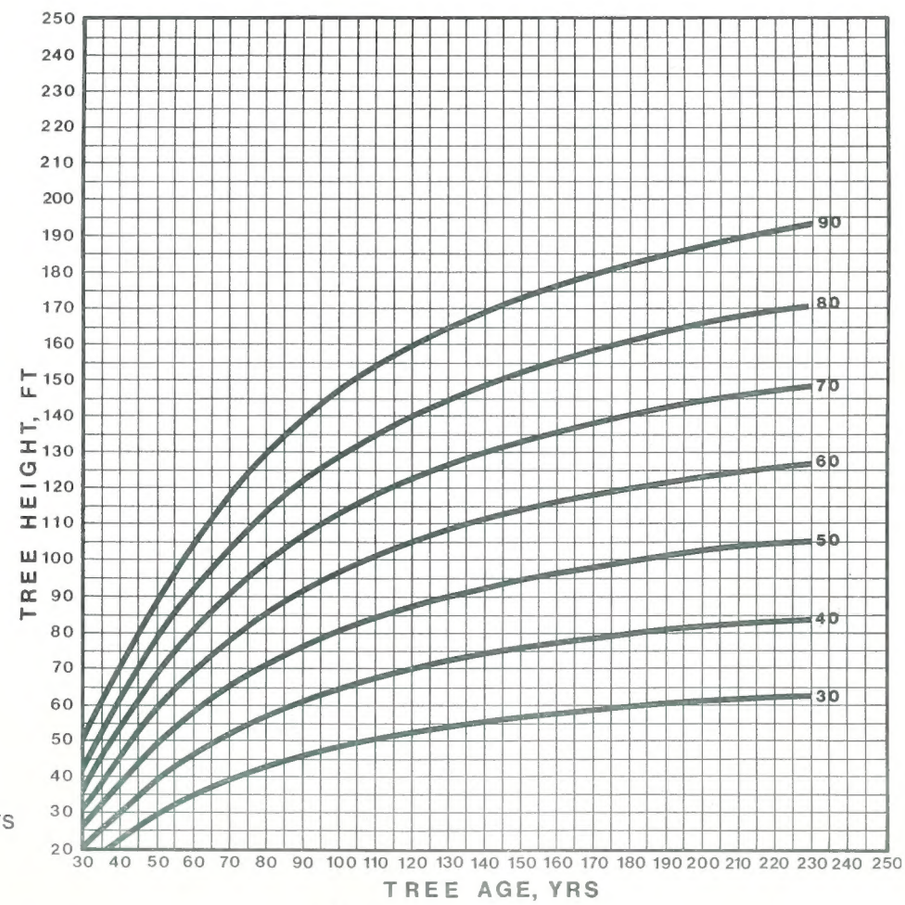
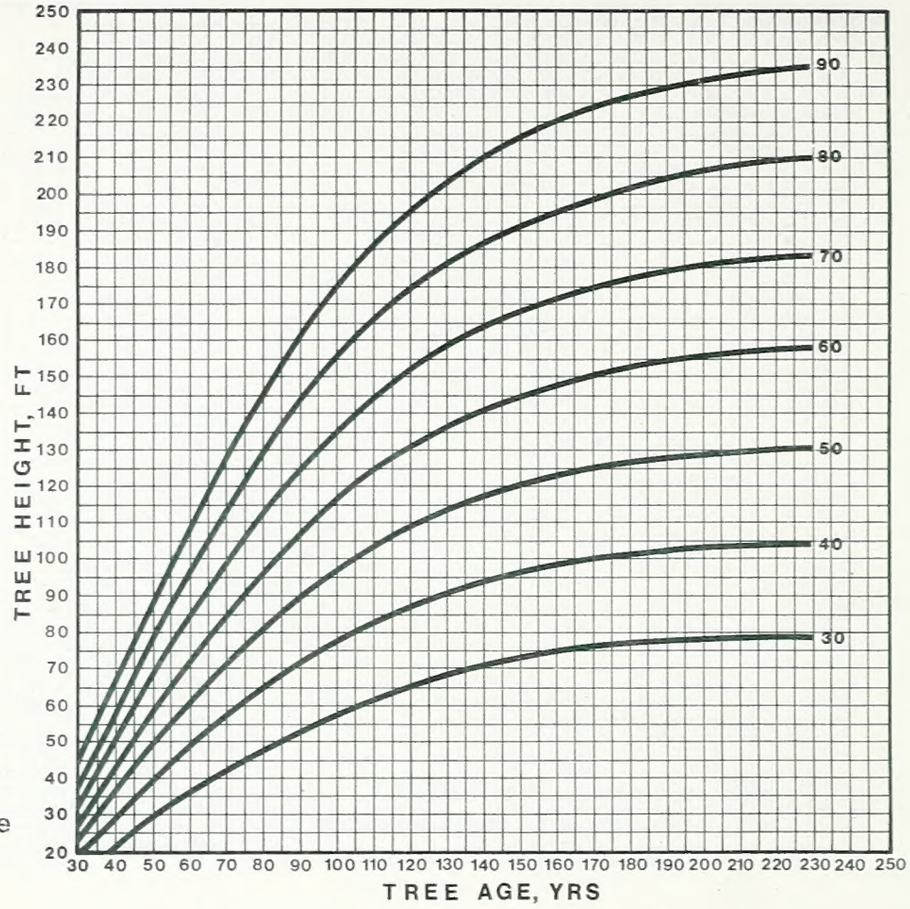


Ponderosa pine. Lynch's (1959) site curves; index age is 50 years total age (7 years added to breast height age).



Western larch. Schmidt and others' (1976) site curves; index age is 50 years total age (5 years added to breast height age).

APPENDIX A. (Con.)



Western white pine. Haig's (1932) site curves; index age is 50 years total age (5 years added to breast height age).

Steele, Brian M.; Cooper, Stephen V. Predicting site index and height for selected tree species of northern Idaho. Research Paper INT-365. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1986. 16 p.

Forests in northern Idaho are capable of supporting as many as 10 different tree species on a given site. Comparing site indexes of species across a variety of sites is one method of assessing which species to favor in stand management. From plots across the spectrum of forest environments, site indexes (50-year index age) of species pairs (26 combinations of a possible 36 total combinations for nine species) were shown by regression analysis to be linearly related. Site index values of one species were able to explain between 33 and 85 percent of the variation in the site index of associated species. Because land managers are interested in more than comparative heights at an arbitrary index age, we developed equations for predicting the height of species A from the predictor variables, site index of associated species, and the age of species A. Graphical solutions of these equations and site index curves are provided for those without ready access to mathematical solutions.

KEYWORDS: site index predictions, height growth predictions, northern Idaho

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

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